# Spitzer's Model for Dealing with the End of the Cryogenic Mission

Suzanne R. Dodd*, Lisa Storrie-Lombardi*, and Charles P. Scott^

*Spitzer Science Center
California Institute of Technology
M/S 314-6, 1200 E. California Blvd, Pasadena, CA, 91125, USA

^Jet Propulsion Laboratory
California Institute of Technology
MS 264-767, 4800 Oak Grove Blvd, Pasadena, CA, 91125, USA

## ABSTRACT

The Spitzer Space Telescope is a cryogenically cooled telescope operating three instruments in wavelengths ranging from 3.6 microns to 160 microns. Spitzer, the last of NASA's Great Observatories, was launched in August 2003 and has been operating for 4.5 years of an expected 5.5 year cryogen mission. The highly efficient Observatory has provided NASA and the science community with unprecedented data on galaxies, star formation, interstellar medium, exoplanets, and other fundamental astronomical topics. Spitzer's helium lifetime is predicted to end on April 18, 2009, with an uncertainty of +/- 3 months. Planning for this cryogen end involves many diverse areas of the project and is complicated due to the uncertainty in the actual date of helium depletion. This paper will describe how the Spitzer team is accommodating the unknown end date in the areas of observation selection, planning and scheduling, spacecraft and instrument monitoring, data processing and archiving, and finally, budgeting and staffing. This work was performed at the California Institute of Technology under contract to the National Aeronautics and Space Administration.

Key Words: Spitzer Space Telescope, Operations, Mission Lifetime

## 1. INTRODUCTION

### 1.1 Mission overview

The Spitzer Space Telescope is the fourth and final of NASA's Great Observatories. Launched from Cape Canaveral, Florida, on August 25, 2003, the Observatory is designed to observe and explore the universe in the infrared at wavelengths ranging from 3.6 to 160 microns. The Spitzer Observatory (figure 1) consists of a Cryo-Telescope Assembly (CTA), spacecraft, and three science instruments: the Infrared Array Camera (IRAC), the Infrared Spectrograph (IRS), and the Multiband Imaging Photometer for Spitzer (MIPS). Each instrument consists of a cold assembly mounted in the cryostat and warm electronics mounted in the spacecraft bus. The science instruments cannot be used simultaneously; only one instrument can be powered on at a time. The CTA has an outer shell that radiates to cold space in the anti-Sun direction, and is shielded from the Sun by the solar panel assembly. The Observatory is in an earth trailing, heliocentric orbit, which eliminates the effect of heat from the Earth.

Observatory Operations: Strategies, Processes, and Systems II, edited by Roger J. Brissenden,
David R. Silva, Proc. of SPIE Vol. 7016, 70160D, (2008) · 0277-786X/08/$18 · doi: 10.1117/12.788131

One of Spitzer's novel cost-saving design features was that it employed a warm launch architecture. The science instrument cold assemblies were in contact with the superfluid helium bath and were held at operating temperature from well before launch, but the telescope was launched at ambient temperature and cooled by a combination of radiation and helium venting from the cryostat to 5.7 K over a period of 45 days. This design permitted Spitzer to have a cryogen lifetime requirement of 2.5 years, with a lifetime goal of 5 years.

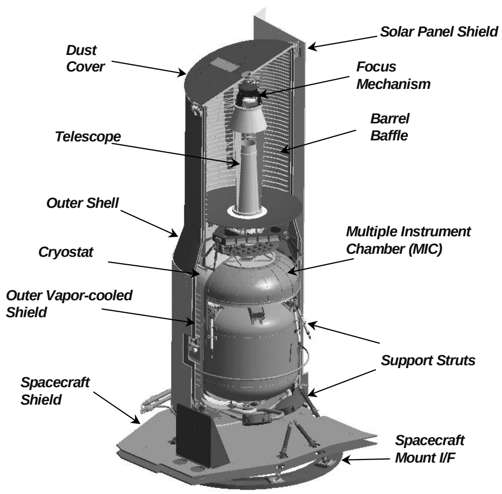


Fig. 1a. Spitzer Observatory Graphic

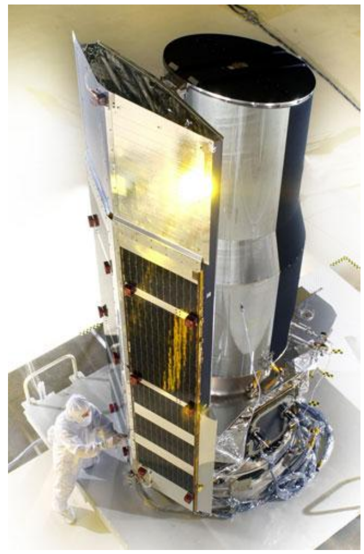

Fig. 1b. Spitzer Observatory at Lockheed Martin

## 1.2 Operations organization

The Spitzer flight operations organization has two components – the Mission Operations System (MOS) at the Jet Propulsion Laboratory (JPL) and at Lockheed Martin in Denver, where the spacecraft engineering functions are performed, and the Spitzer Science Center (SSC) located at Caltech, where the science operations are performed (figure 2). The MOS is responsible for the sequence integration and verification, spacecraft health and safety monitoring, and command generation and data receipt. The SSC is responsible for overseeing the observing proposal process, mission planning and science observation scheduling, instrument performance monitoring, data processing and archiving, science community support, and science research funding. These two teams have worked in concert over the past 4.5 years to ensure both the continued excellent health of the Spitzer Observatory and the exceptional science efficiency of the Observatory.

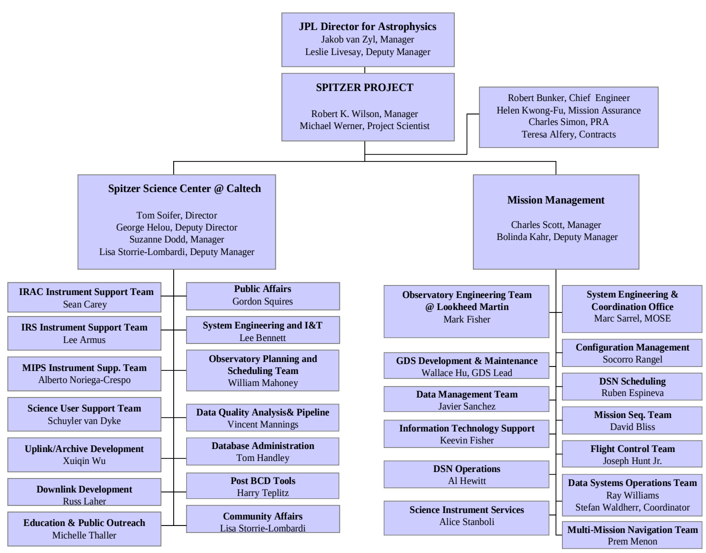


Fig. 2. Spitzer Project Organization

### 1.3 Science efficiency

Science efficiency is the measure of time spent directly supporting the collection of science data. As defined for Spitzer, this includes the time spent slewing to an observation and the time used for science instrument calibrations as well as the time spent executing observations for observers. It does not include spacecraft calibration time, data downlinks, gaps or anomalies. The science efficiency has risen steadily over the 4.5 years of nominal operations (figure 3). It has increased from 84% in year 1, 87% in year two, 88% in year 3, 91% in year 4, to 90% currently in year 5 (table 1). The Spitzer project goal for science efficiency is 90%, which the project has met for the past two years.

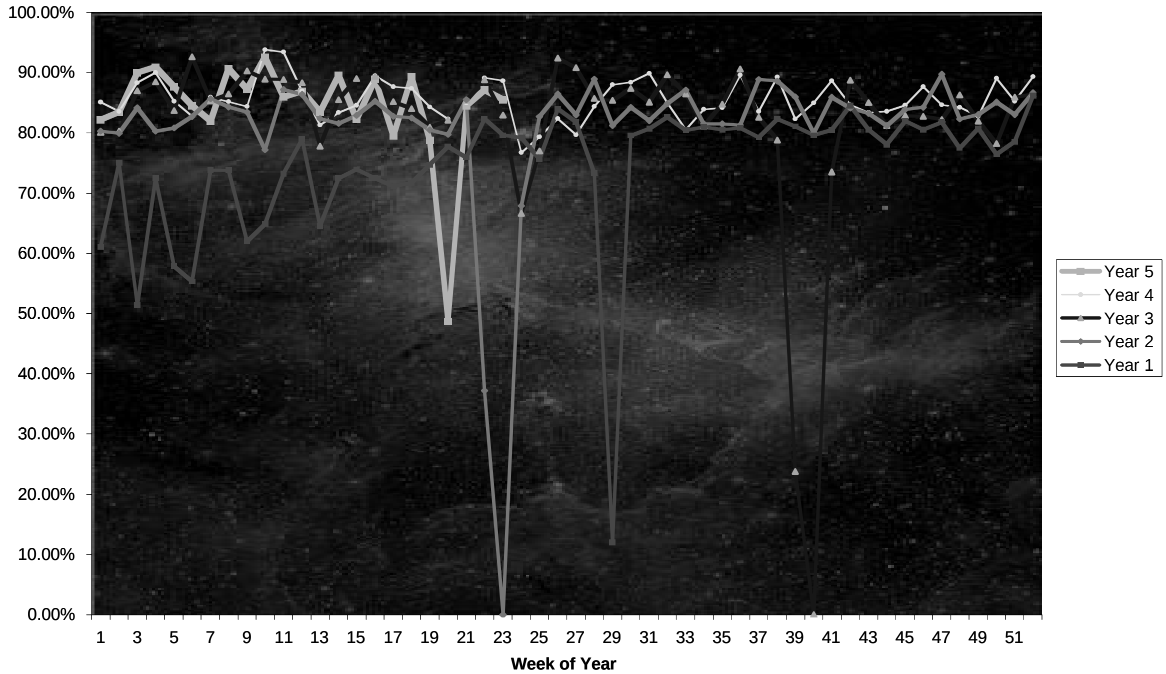


Fig. 3. Percentage of Science and Science Instrument Calibrations per Weekly Schedule.
Large dips correspond to major anomalies.

| Mission Year | % Science | % Science Instrument Calibrations | % Spacecraft Calibrations | % Downlinks | % Slews | % Anomalies | % Gaps |
|---|---|---|---|---|---|---|---|
| Year 1 | 59 | 16 | 4 | 8 | 9 | 3 | 1 |
| Year 2 | 68 | 12 | 2 | 7 | 7 | 3 | 1 |
| Year 3 | 72 | 10 | 1 | 6 | 6 | 4 | 1 |
| Year 4 | 76 | 9 | 1 | 6 | 6 | 1 | 1 |
| Year 5* | 74 | 10 | 1 | 6 | 6 | 2 | 1 |
| Average | 70 | 11 | 2 | 7 | 6 | 3 | 1 |

* first 23 weeks

Table 1. Science Efficiency by Year

## 2. CYROGEN OPERATIONS

### 2.1 Cryogen lifetime

Spitzer's cryogen lifetime is predicted to end on April 18, 2009, with an uncertainty of +/- 12 days (two sigma). This is based on a linear extrapolation of mass measurements since January 2005 (figure 4). Historically, this method has had errors as large as +/- 5%, which is equivalent to three months for Spitzer. Thus the Spitzer cryogen mission could end as early as January 18, 2009 or as late as July 18, 2009. The official end of cryogen will be when the Cryogen Tank Internal sensor #2 meets or exceeds 4.0K. The spacecraft will enter Standby Mode due to the Cryogen Tank Assembly temperatures exceeding limits, which may occur before or after sensor #2 exceeds 4.0K.

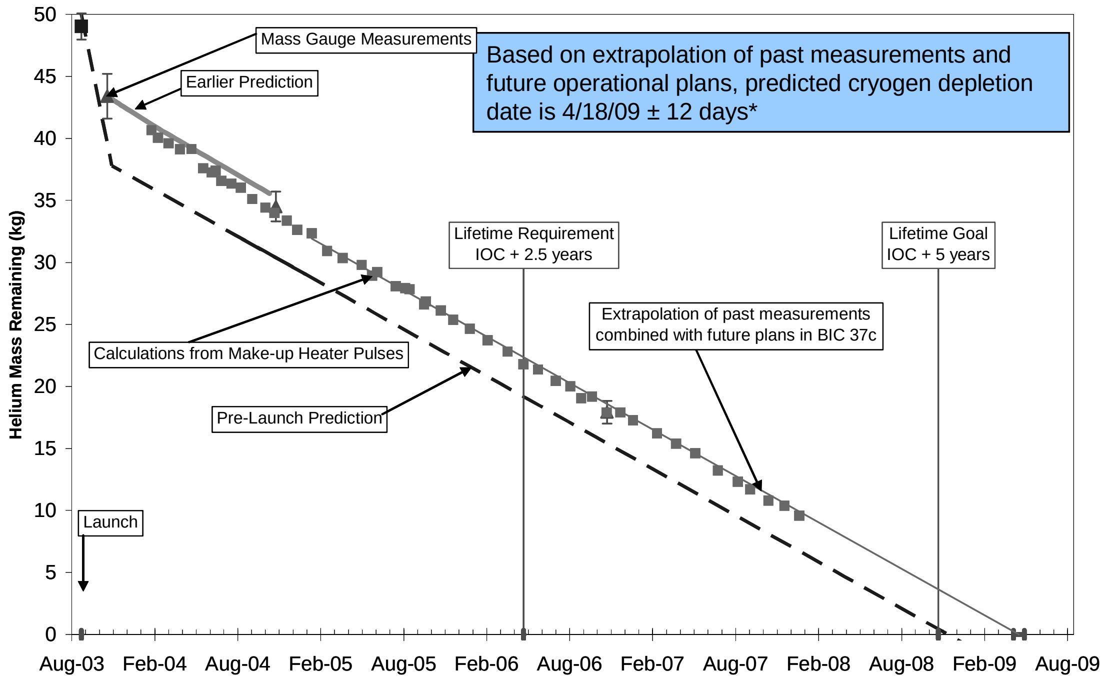


Fig. 4. Predicted Cryogenic Depletion

Planning for the end of a space based mission is a non-trivial process which includes planning for final data taking for science goal completion and final calibrations for accurate data processing. Add to this the problem of a three month uncertainty in the cryogen end date, and one can quickly see how complicated the planning process becomes.

### 2.2 Observation selection

The General Observer Cycle 5 proposal call represented the last call for proposals for the Spitzer cryogen mission. Because of this, special instructions were given in the Call for Proposal and in the selection criteria given to the Time Allocation Committee members. Proposals were encouraged that: fill scientific gaps in the Spitzer scientific program, pursue follow-on observations of uniquely Spitzer discoveries, and exploit the unique capabilities of Spitzer during the final cryogen observing cycle. The archival value of the proposed observations was added as an explicit selection criterion. Scientific merit remained the primary selection criterion.

Due to the uncertainty in the end date of the cryogen mission, it is important to ensure that there are enough observations in the scheduling pool to last through the latest possible end date. A full year's worth of observations (enough to run through July 2009) was selected with the expectation that slightly more than half will be executed. There were no large programs (greater than 200 hours) allowed, and no second-look observations permitted. Observations are being scheduled based on their science priority (described in the next section). Finally, there is no carry over of selected proposals in to the proposed Warm Spitzer mission. If NASA decides to fund a Warm Spitzer Mission, a new General Observer call, Cycle 6, will be released in the summer of 2008.

### 2.3 Observation scheduling

The Time Allocation Committee was asked to rank proposals based on executing the best science now, regardless of whether there might be a warm mission. All observing programs were assigned a scheduling priority: priority 1 equals the top 25% of selected hours, priority 2 equals the next 25%, priority 3 equals the bottom 50% of selected hours. It is expected that Spitzer will execute the priority 1 and 2 observations, with the priority 3 programs essentially used as filler in the observing schedule. Observations from the General Observer Cycle 4 pool which have not been executed will be carried over into the Cycle 5 observing pool, with their execution priority increased by one level (Cycle 4 priority 2 becomes Cycle 5 priority 1).

The Basic Instrument Campaign cycle for Spitzer is ~5 weeks: 10 days of IRAC, 12 days of MIPS, and 12 days of IRS. This rotation of instrument usage provides Spitzer with the most efficient use of helium, and is one of the primary reasons the mission lifetime has been extended out to 5.5 years. In order to accommodate the priority 1 observations, which includes a number of heavily constrained exoplanet observations, this instrument usage pattern has been adjusted, incorporating longer IRS campaigns and shorter (or deleted) IRAC campaigns. Thus to accommodate the highest priority observations before the helium runs out, the efficiency of Spitzer will decrease some what from the greater than 90% achieved during General Observer Cycle 4. Finally, this scheduling process is more labor intensive than past cycles due to the need to ensure the highest priority observations are executed.

### 2.4 Instrument and spacecraft calibrations

Along with the last cycle of science observations, scientists and engineers have been planning the execution of the last set of calibrations which will be used for the final processing of the cryogen mission data. The three instruments (MIPS, IRAC, IRS) have completed most of their final bias and temperature setting updates and flat field measurements in preparation for the execution of Cycle 5 observations. There will not be a full-blown recalibration of the operating parameters of any of the instruments, unless there is an anomaly that causes unanticipated degradation of performance (e.g. a solar storm, swap to backup side of the electronics, etc). Similarly, the only planned spacecraft calibrations remaining are a final Wide Angle Sun Sensor calibration and a High Gain Assembly boresight alignment planned for this fall, about 6 months before the nominal mission end date.

## 3.0 PRIME MISSION CLOSEOUT

### 3.1 Heritage archive

If no warm mission operations are approved for post FY09, the Spitzer Observatory operations will cease when the cryogen is exhausted. The expected cryogen depletion date is April 18, 2009. The earliest cryogen mission end date is January 18 and the latest end date is July 18. The highest priority for the prime mission closeout is to assure the lasting heritage of Spitzer. The major component of the Spitzer legacy is the Heritage Archive.

The Spitzer Heritage Archive is the lasting legacy of the Spitzer mission and it will be a source of unprecedented infrared data for decades (table 2). During the closeout phase, the Heritage Archive must be completed and then populated with the final processed data. In order to leverage new science from the archive, quality and uniformity over the entire archive is critical. The final pipeline processing, which will occur after the cryogen mission ends, will have optimal calibration and minimal artifacts.

| Type of Data | # of Observations | Hours of Data | # of Programs | Hours of Data in Legacy/Large Projects |
|---|---|---|---|---|
| MIPS Images | 16,220 | 12,250 | 720 | 6350 |
| IRAC Images | 12,944 | 9790 | 760 | 5950 |
| IRS Spectra | 16,060 | 13,180 | 833 | 4807 |

Table 2. Predicted Spitzer Archive Contents at the End of the Cryogen Mission

The Spitzer Heritage Archive encompasses not only the final processed data, but also the final set of mission documentation: instrument calibration documents, data processing history and description documents, observing and engineering schedules, data analysis documentation, and user tool documentation. Completion of this whole set of documentation is critical to ensuring that the full scientific potential of the Spitzer archive is realized.

The completion of the Spitzer Heritage Archive results in the delivery of the complete Spitzer data set and supporting documentation to the Infrared Science Archive (IRSA). Spitzer unique user tools for coaddition and mosaicing of images, extracting flux and wavelength calibrated spectra, and point source extraction for aperture photometry will also be handed over to IRSA. The transition of the Heritage Archive to IRSA will be completed by the end of the prime mission close out in March 2011. At this point in time, IRSA becomes responsible for the curration of the data archive, documentation, and user tools. IRSA is then also responsible for all on going science user community support.

### 3.2 Project closeout

The Mission Operations System and Spitzer Science Center scheduling components will be closed out at the end of September 2009. If no Warm Spitzer Mission is funded by NASA, the Spitzer spacecraft will be placed into Safe Mode and will run fully on the solar array power. This will allow NASA to recontact the spacecraft if at some time in the future they desired to do so.

The SSC and JPL Project office will complete closeout operations at the end of March 2011. During the close out phase, there will be on going support to the science community for reduction and analysis of their Spitzer data and archival research. As mentioned above, data analysis tools and documentation will be completed, and the Heritage Archive will be complete and populated with the final processed data.

The elements of the prime mission closeout activities, consistent with NASA and JPL policies, will include: cataloging and archiving all project records, completing all close out documentation including a flight operations phase summary and key lessons learned, and close out of contracts and residual funds. NASA will provide minimal support to JPL after March 2011 to support monitoring and close out of the data analysis contracts that extend past the project end date.

### 3.3 Staffing and budget

The current Spitzer budget supports Observatory operations until mid July 2009. This covers the longest duration cryogen mission Spitzer could have. The budget plans call for rolling off all operations staff 2.5 months after the end of the prime mission. If the cryogen mission ends earlier, operations staff will be let go earlier, and excess project funds will be returned to NASA.

User community funding is also affected by the cryogen mission end date. There is $4000k set aside to support a final archival research call assuming a mid April 2009 prime mission end. If the prime mission extends until July 2009, the $4000k will be used to fund data analysis of the additional cryogen observations. An early prime mission end would allow for both a final archive research call and additional user community funding being returned to NASA. Table 3 shows both the staffing and budget dependency on the prime mission end date.

| Prime Mission End Date | Final Processing Start Date | Final Processing End Date | Operations Staff Roll Off Date | Operations Budget Savings | Funds for Archival Research |
|---|---|---|---|---|---|
| April 18, 2009 | May 1, 2009 | March 31, 2011 | July 1, 2009 | $2500k | $4000k |
| July 18, 2009 | May 1, 2009 | March 31, 2011 | September 30, 2009 | $0 | $0 |
| January 18, 3009 | February 1, 2009 | March 31, 2011 | April 1, 2009 | $4584k | $5000k |

Table 3. Staffing and Budget Dependency on Cryogen Mission End Date

Prime mission close out will begin no later than May 1, 2009. The prime mission close out end date is March 31, 2011, regardless of the exact date of cryogen depletion. If the prime mission runs longer than May 1, SSC staff will be squeezed due to continuing Observatory operations while commencing work on the close out activities. However, it is hoped that the atmosphere will be positive due to the extended cryogen lifetime. An early cryogen end allows for non-operations resources to put toward creating enhanced data products for the archive and improved documentation. The fixed end date of March 31 will help with staffing retention in a downsizing environment. Providing schedule certainty when the prime mission ends will make it more likely that experienced staff don't leave the project earlier than they have to based on not knowing when their job will end. Particularly for science staff, with the annual nature of the science hiring cycle, knowing the end date well in advance with relative certainty will make it easier for the project to retain the best performers. This in turn will result in the highest quality final archive.

The unfortunate scenario at both JPL and Caltech is that there are not enough new funds coming into these organizations to place all the staff who will be rolled off as the Spitzer project ends. The project currently employees 80 people at the SSC and 34 at JPL and Lockheed Martin. Over the next three years, staffing will be ramped down to zero, assuming no Warrm Spitzer mission. This precipitous drop in personnel comes with a concomitant morale problem. Keeping the best employees around to support the Heritage Archive and cryogen mission close out activities will be a challenge. As people leave these organizations, unique skill sets and valuable years of experience will be lost, putting JPL and Caltech's future ability to attract and operate new missions at risk.

# 4. THE WARM MISSION

## 4.1 Warm mission capabilities

After the completion of the cryogen mission, the Spitzer Observatory will remain a unique asset, capable of operating at full sensitivity and efficiency in the IRAC bands at 3.6 and 4.5 microns. All spacecraft systems are in excellent health and remain fully redundant. Warm Spitzer offers the capability for extensive photometry and mapping at 3.5 and 4.5 microns with orders of magnitude more sensitivity than any other platform until the launch of the James Webb Space Telescope. Major science themes for a warm mission include characterization of extrasolar planets and planetary systems, cosmological imaging surveys of moderate depth and large area, deep cosmological surveys of small areas, and determining the size of near earth asteroids. This opportunity to take additional data with Warm Spitzer continues until early 2014, when the Observatory moves out of communications range with the Earth.

The Spitzer project presented a Warm Spitzer mission to the NASA Astrophysics Division Senior Review Panel this past April (2008). The proposal included two options: a nominal warm mission lasting 3.5 years and costing $79,731k, and an optimal warm mission lasting 4.5 years and costing $160,577k. Each of these proposals includes in it significant funding to the user community for data analysis and archival research: $22,500k for the nominal mission and $72,250k for the optimal mission. A comparison of these two options is in table 4.

| Attribute | Optimal | Nominal |
|---|---|---|
| Science Selection | Peer Review | Same |
| Exploration Science | >5000 hours per year | Same |
| Total Observing Time | 29-31,000 hours | 21-23,000 hours |
| Small Project Opportunity | 4500-6700 hours | 3200-4800 hours |
| Observing Efficiency | Full capability (> 90%) | Accept Modest Decrease(<5%) |
| Rapid Response Target of Opportunity support | 10-12 per year | ~ 1 per year |
| Science User Support | Reduced by 50% from current level | Same |
| Community funding for Cryo-Archive Research | Fully Exploited for ~ 5 years | Current level until cryo-archive completed (FY11) |

Table 4. Compariion of the Nominal and Optimal Warm Spitzer Mission

As of this writing, the Spitzer project has not heard whether the Warm Spitzer mission proposal will be funded. However, the project is moving forward with the planning necessary to implement a warm mission if approved. These activities include preparing a warm IRAC checkout sequence, modifying command blocks, and updating operations procedures. If approved, the Warm Spitzer mission will continue to enable major new science investigations which are both unique and compelling.

## 5. CONCLUSIONS

The Spitzer Space Telescope has become an essential element in the fabric of astronomical research. In 4.5 years of operations, more than 1100 referred papers have been published based on Spitzer data. But alas, all good things must come to end. For the Spitzer cryogen mission, that end will come around mid April, 2009, when the helium runs out. The 6 month variance in the actual end date means the project must have multiple plans in place to deal with a mission that finishes early, late, or right on prediction. The lesson that future missions can take away from Spitzer's experience is to start planning for the mission end early. It will take time and resources to complete the final archive and associated documentation, and project staff may not stick around until the end of the mission to complete those tasks. In order to ensure Spitzer's scientific legacy, careful planning for observation scheduling, data processing and archiving, and budget and staffing is required. If a Warm Spitzer mission is approved, the project will be able to provide science return equivalent to a small explorer mission (SMEX) with no significant technical or cost risks.

## ACKNOWLEDGEMENTS

The success of the Spitzer Mission is due to the efforts of the outstanding staff of the Spitzer Science Center, the Jet Propulsion Laboratory, and Lockheed Martin Aerospace. In addition, the many engineers and scientists involved in the development of the instruments at Ball Aerospace & Technologies Corp., the University of Arizona, Cornell University, and the Smithsonian Astrophysical Observatory are to be commended for the exceptional durability and quality of their instruments. It is a privilege to work in such a talented and dedicated organization. This work was performed at the Infrared Processing and Analysis Center at the California Institute of Technology under contract to the National Aeronautics and Space Administration.

## REFERENCES


1. S.R. Dodd, D. Levine, *The Spitzer Space Telescope's Performance: Getting the most out of a Great Observatory*, SPIE 2006 Conference, Orlando, Florida, May 24-31, 2006, [6702-2]
2. B.T. Soifer, M.W. Werner, R. K. Wilson, *Warm Spitzer Mission*, NASA Astrophysics Division Senior Review Proposal, March 12, 2008.
3. Marc Sarrel, Joseph Hunt, *Evaluating Requirements on the Spitzer Mission Operations System Based on Flight Operations Experience*, SPIE 2008, June 23-27, 2008, [7016-61]
4. W. A. Mahoney, S. Comeau, L. J. Garcia, D. B. McElroy, D. S. Mittman, J. C. O'Linger, S. R. Tyler, *Spitzer Scheduling Challenges: Cold and Warm*, SPIE 2008, June 23-27, 2008 [7016-67]
5. G.B. Berriman, *The NASA/IPAC Infrared Science Archive (IRSA) as a Resource in Supporting Observatory Operations*, SPIE 2008, June 23-27, 2008, [7016-44]
6. C. P. Scott, B. E. Kahr, M. A. Sarrel, *Spitzer observatory operations: increasing efficiency in mission operations*, SPIE 2006 Conference, Orlando, Florida, May 24-31, [6270-49]
7. R. K. Wilson, C. P. Scott, *NASA's Spitzer Space Telescope's operational mission experience and lesson's learned*, SPIE 2006 Conference, Orlando, Florida, May 24-31, 2006, [6270-01]